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Use of a Portable Electric Barrier to Estimate Chinook Salmon Escapement in a Turbid Alaskan River

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Abstract.—We developed a portable electric barrier to aid in the capture of adult chinook salmon *Oncorhynchus tshawytscha* undergoing spawning migrations up a turbid stream in south-central Alaska. In 1981, we tagged and released 157 chinook salmon after diverting them from the main-stem Killey River into a conventional trap with the aid of the electric barrier. On the basis of returns of tagged salmon to Benjamin Creek, a clear-water tributary of the upper Killey River, we estimated spawners in the drainage to number 8,000 fish. Two different statistical approaches to the mark–recapture data yielded similar estimates. Through several modifications of the electric barrier, we were able to reduce mortality associated with the barrier's use.

In many Alaskan streams, turbid waters and geographical remoteness impede attempts to determine how many salmon escape the fisheries to spawn. These factors can preclude direct counts of fish and reduce sampling success. Escapement data are essential for sound decisions in the management of anadromous salmonids, and our objective was to find a way to estimate the number of chinook salmon *Oncorhynchus tshawytscha* migrating up a turbid Alaskan river to spawn.

The Killey River is a glacially turbid tributary of the Kenai River in south-central Alaska that is fed, in part, by a clear-water stream, Benjamin Creek (Figure 1). Telemetry studies and stream surveys (Burger et al. 1985) indicated that early-run chinook salmon migrate 72 km through an intense sport fishery (Hammarstrom 1981) in the Kenai River each summer to spawn in the Killey River and in Benjamin Creek. Spawners could be counted in the clear waters of Benjamin Creek but not in the turbid Killey River. With the aid of a portable electric barrier, we diverted some Killey River migrants into a trap during 1981 for tagging and subsequent release. We estimated total escapement from the ratio of tagged to untagged chinook salmon counted in Benjamin Creek.

Electric barriers have been used by several researchers to guide, divert, or control fish migrations (Applegate et al. 1952; Andrew et al. 1955; Thompson 1960; Maxfield et al. 1969). Other devices, including electric screens and fences, have been described by Halsband (1967) and Bell (1973). The use of an electric field to divert adult salmon into a fish ladder for the purpose of obtaining eggs and sperm was described by Burrows (1957), and this practice has continued to be used at several U.S. Fish and Wildlife Service hatcheries in the northwestern USA. The electric field is generated by a row of electrodes suspended from an electrified cable spanning the river. Because this system was too cumbersome for our purpose, we designed a simple electric barrier suitable for temporary use at a remote site.

Study Site

The site on the Killey River where we intercepted fish for tagging (9 km above the confluence of the Killey and Kenai rivers) was divided into a major and minor channel by an island (Figure 2). The major channel was 27 m wide. This channel was unobstructed and carried about 85% of the river flow. We constructed the electric barrier across this channel perpendicular to the water flow and about 10 m upstream from the lower entrance to the minor channel (Figure 2). At low flow (mid-May 1981), discharge through the major channel was about 16 m^3/s, water velocity was 0.6–1.5 m/s, and the maximum depth was 1 m. As the season progressed, the water level rose and reached a depth of about 2 m at midchannel in August.

We installed a conventional weir and trap in the minor channel, an area about 100 m long and 13 m wide (Figure 2). A partial log jam at the up-

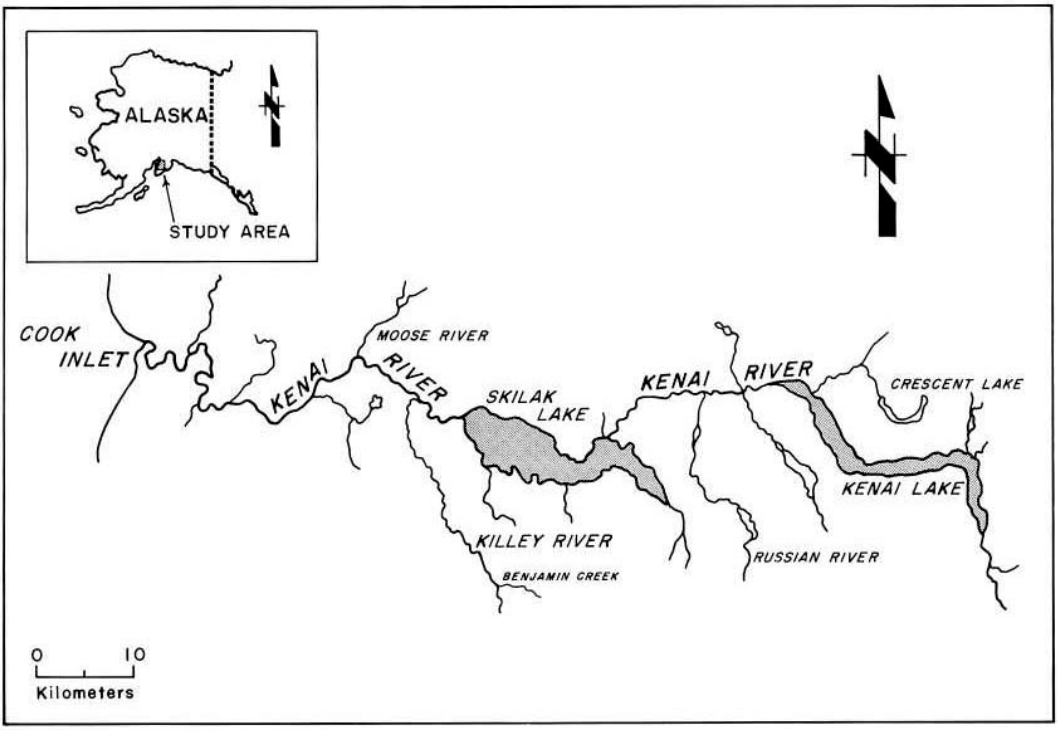

FIGURE 1.—Location of the Kenai and Killey rivers in south-central Alaska.

stream end of the channel protected the weir by preventing the entry of logs and other floating debris. At low flow, discharge through this channel was 2.8 m^3/s and the maximum depth was 1.5 m. Water temperature (6°C) and conductivity (40 $\mu S/cm$) were consistently low.

Methods

The electric barrier was composed of two 27-m lengths of 9.5-mm galvanized wire rope that constituted the electrodes. These were connected to a diesel-powered generator (1,800 revolutions/min, 4,000 W) and a Smith-Root[1] type VI A electrofisher unit. We tried several electrode arrays and electrical settings. The most successful consisted of direct current at 168 V, a 3.7-ms pulse width, 120 pulses/s, and 1-A current. The cathode was stretched across the river under water and secured to the bottom with bags filled with coarse gravel. The anode was submerged in shallow water upstream of the cathode and parallel to the stream bank (Figure 2). We operated the generator continuously for about 70 h, and then turned it off for about 100 h each week after 21 June 1981.

The conventional weir in the minor channel was based on the design of Anderson and McDonald (1978). We marked fish captured in the trap with serially numbered Petersen disc tags. We used tags of a different color for each tagging interval so that time of tagging could be determined when a tagged fish was sighted. The tags were attached near the base of the dorsal fin by standard fish-marking techniques. We recorded sex and length (mideye to fork of caudal fin) for all fish captured.

We conducted the recovery survey in Benjamin Creek, a spawning area that is 1,200 m long, less than 30 m wide, and less than 1.5 m deep. The clear water there enabled us to count spawning fish without recapturing them. Four biologists traveled by helicopter to the confluence of Benjamin Creek and the Killey River three times (22 July, 30 July, and 5 August 1981) to enumerate spawning fish. Two persons on each bank walked upstream during each survey to count tagged and untagged chinook salmon and record the colors of the tags seen. Approaching fish from downstream enabled us to see the fish before they sighted us and fled. We obtained fairly reliable counts because the salmon

[1] The mention of trade names does not denote endorsement by the U.S. Fish and Wildlife Service.

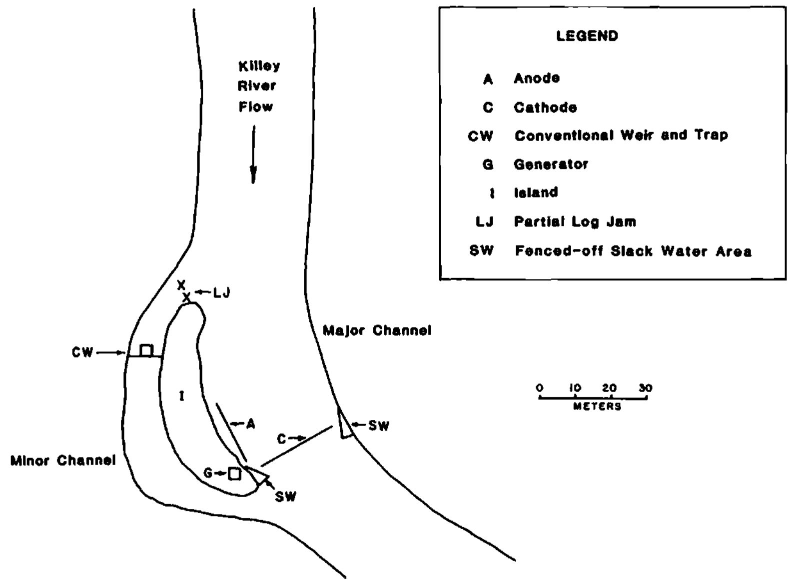

FIGURE 2.—Sketch of the lower Killey River, Alaska, showing divided stream channel and locations of electric barrier and conventional weir and trap where chinook salmon were captured for tagging.

tended to flee downstream without disturbing uncounted fish upstream. We netted tagged fish when possible for determination of sex and length.

We used two different statistical approaches to estimate adult escapement. For the first method (Schaefer 1951), we used the notation of Ricker (1975), as follows.

- M_i = number of fish marked in the ith period of marking.
- M = ΣM_i, the total number of fish marked.
- C_j = number of fish examined for tags in the jth period of recovery.
- C = ΣC_j, the total number of fish examined for tags over all recovery periods.
- R_{ij} = number of fish tagged in the ith tagging period that were sighted in the jth recovery period.
- R_i = total number of sightings of fish tagged in the ith period of tagging over all recovery periods.
- R_j = total number of tagged fish from all tagging periods sighted during recovery period j.
- R = ΣR_j, the total number of tagged fish sighted over all recovery periods.

We tabulated these data; for each cell of the table, we estimated the portion of the population available for marking in period i and available for recovery in period j. The sum for all cells was the total population:

$$\hat{N} = \Sigma\ [R_{ij}(M_i/R_i)(C_j/R_j)].$$

Because all fish were tagged before the first recovery survey, a simple Petersen estimate (Ricker 1975) also was used: $\hat{N} = M(C/R)$. We developed 95% confidence limits by treating R as a Poisson variable. A Poisson chart (Ricker 1975) was used to determine the limits that were substituted into the Petersen equation.

Our attempts to divert chinook salmon resulted in serious injury or death to some fish. Injuries to these fish caused erratic swimming behavior, burn marks, ruptured blood vessels, and broken vertebrae. We traveled the 9 km of Killey River between the electric barrier and the Kenai River twice daily by boat to count killed or injured fish and determine their sex, length, and cause of injury. If we saw an injured fish that we could not capture for inspection, we assumed it had been injured by contact with an electrode and we counted it as a killed fish. The turbid water made accurate counts impossible, and it is unlikely that we saw all of the dead fish. We assumed our counts to be proportional to the number of fish killed and used the counts to evaluate the effects of changes to the electric barrier, but not as an estimate of the absolute number of fish killed.

Results and Discussion

We marked 157 adult chinook salmon in the lower Killey River during four tagging periods (Ta-

TABLE 1.—Tagging dates, sex, and mean lengths (mideye to fork of caudal fin) of 157 chinook salmon tagged in 1981 at a weir in the lower Killey River, Alaska.

Tagging period and dates	All fish			Males			Females		
		Length (cm)			Length (cm)			Length (cm)	
	N	Mean	SD	N	Mean	SD	N	Mean	SD
1 13–21 Jun	23	89	8	3	79	7	20	90	7
2 22–28 Jun	19	87	11	2	77	26	17	88	7
3 29 Jun–5 Jul	80	86	10	30	80	11	50	89	7
4 6–12 Jul	35	77	16	16	67	13	19	85	12
Total	157			51			106		

ble 1). We subsequently examined 1,241 fish (ΣC_j, Table 2), of which 24 were tagged (ΣR_j, Table 2). These numbers were sufficient to yield a statistically unbiased population estimate (Robson and Regier 1964; Ricker 1975). The estimated chinook salmon population of the Killey River in 1981 was 7,949 fish by Schaefer's method (Tables 2, 3) and 8,100 fish by the Petersen method. The 95% confidence interval was $5{,}500 \leq \hat{N} \leq 13{,}000$.

For a mark–recapture study to give a valid population estimate, either the marked fish or the total recovery effort must be randomly distributed over the population being sampled. The mean lengths of all tagged fish and all killed fish were 84 cm and 98 cm, respectively (Tables 1, 4). Also, the proportions of males were 32% among tagged fish and 67% among killed fish (Tables 1, 4). Because the populations of tagged fish and killed fish were dissimilar, we concluded that the tagging scheme was nonrandom and that large fish, especially males, were more likely to be killed than smaller ones. Nevertheless, unequal vulnerability of fish of different sizes to sampling gear does not result in a large error in a population estimate (Ricker 1975).

We assumed random mixing of tagged and untagged fish in the recovery area, although there was potential bias from sampling only one geographical area. Of the 24 tagged fish observed at Benjamin Creek, seven were recaptured and identified. The mean length (85 cm) of the recaptured tagged fish was similar to that of all tagged fish (84 cm). We cannot prove that tagged fish were as likely to reach Benjamin Creek as untagged fish, but the evidence supports the hypothesis that, if any bias existed, it was different from the tagging bias (i.e., bias based on size). Also, making surveys at Benjamin Creek on three occasions reduced the effect of bias resulting from nonrandom mixing if there was stratification over time. Further study of the randomness of the recovery effort would be useful in evaluating population estimates like ours. In particular, it would be helpful to know if an encounter with the electric barrier affects subsequent migratory behavior of the fish.

We modified the design and operation of the barrier several times during the season to address obvious problems. We eliminated areas of low water velocity in the electric field on 28 June by fencing off the shallow, slow-moving water near the banks with Vexar netting; the netting was placed in the stream parallel to the flow (Figure 2) to offer minimum resistance to the water current. This step was required because fish stunned by the electric field lost muscular control and became immobilized. If they were not immediately flushed away by the water current, they were killed. Originally we placed both the anode and cathode across the river, suspended in the water column in par-

TABLE 2.—Numbers of chinook salmon tagged in the lower Killey River and recovered on spawning grounds in Benjamin Creek, Alaska. These data were used to estimate escapement by the Schaefer method (Table 3).

Recovery period (j)	Fish recovered from tagging period (i): 1 13–21 Jun	2 22–28 Jun	3 29 Jun–5 Jul	4 6–12 Jul	Tagged fish recovered (R_j)	Total fish recovered (C_j)	C_j/R_j
1 (22 Jul)		1	6		7	318	45.4
2 (30 Jul)	1	1	6	5	13	614	47.2
3 (5 Aug)			1	3	4	309	77.3
Tagged fish recovered (R_i)	1	2	13	8	24	1,241	
Total fish tagged (M_i)	23	19	80	35			
M_i/R_i	23.0	9.5	6.2	4.4			

TABLE 3.—Numbers of chinook salmon passing the Killey River tagging station in 1981 estimated by the method of Schaefer (1951).

Recovery period	Fish passing during tagging period: 13–21 Jun	22–28 Jun	29 Jun–5 Jul	6–12 Jul	Total
1		431	1,689		2,120
2	1,086	448	1,756	1,040	4,330
3			479	1,020	1,499
Total	1,086	879	3,924	2,060	7,949

TABLE 5.—Comparison of the number of chinook salmon deaths with the number tagged during operation of an electric weir on the Killey River, Alaska, in 1981.

Time period	Hours generator was operated	Number of fish: Killed (K)	Tagged (T)	K/T
1–7 Jun	72	0	0	
8–14 Jun	160	8	5	1.6
15–21 Jun	128	10	18	0.56
22–28 Jun	76	15	19	0.79
29 Jun–5 Jul	63	11	80	0.14
6–12 Jul	67	1	35	0.03
Total	566	45	157	0.29

allel, about 5 m apart. On 29 June, using sandbags placed at 5-m intervals, we secured the electrodes to the stream bottom to minimize the likelihood that a fish would contact one of the cables; physical contact was likely to be lethal. Third, we used alternating current from 1 to 28 June and direct current from 29 June to 12 July. These changes were accompanied by a sharp reduction in the ratio of killed fish to tagged fish after 29 June (Table 5).

To ensure adequate escapement of fish that had no contact with the electric barrier, we operated the generator for 76 h or less each week during the final 3 weeks of tagging. On 6 July, we placed the anode perpendicular to the cathode and close to the bank, further reducing the risk of a fish touching one of the electrodes. The overall ratio of known killed fish to tagged fish was 0.29, but the weekly ratio declined to 0.03 by the end of the tagging operation (Table 5).

Management Implications

This paper describes a new application of an electric barrier, simplified for field use, to estimate adult escapement of chinook salmon. We used certain geomorphological features of the drainage system to our advantage. For example, the availability of a vegetated island in the Killey River enabled us to locate the barrier in the vicinity of a side channel where we could construct the conventional weir and trap for catching and tagging fish. Other tagging strategies, such as netting fish, can also be used in conjunction with an electric barrier. The barrier can block and concentrate migrating salmon to facilitate their capture and tagging. Adequate water velocity (1 m/s), and the absence of obstructions are the minimum prerequisites for a safe and positive electric block. We have demonstrated the effectiveness of such a system in a silty, muddy stream that was 27 m wide and 1–2 m deep.

TABLE 4.—Sex and mean length (mideye to fork of caudal fin) of chinook salmon killed by the operation of an electric weir on the Killey River, Alaska.

Sex	N	Number measured	Length (cm): Mean	SD
Male	24	14	100	11
Female	12	12	96	5
Unknown	9			
Total	45	26		

The concentration of spawning adults in a small clear-water stream during the recovery survey was a distinct advantage because the need to actually catch the fish was eliminated. Alternative recovery strategies (for example, carcass counts) are feasible if the watershed is not too large.

Electroshocking of fish can be accomplished with negligible mortality, as demonstrated by Hudy (1985). He observed less than 2% mortality among shocked hatchery trout. The effects of electroshocking on the migratory and spawning behavior of adult salmon are not well known. In the present study, 24 of 157 captured and tagged chinook salmon were observed at the Benjamin Creek spawning area, but the intensity and the extent to which these fish received electric shocks arc unknown. It is known that viable eggs and sperm can be obtained from electroshocked salmon; however, excessive exposure to electric fields can be hazardous to the eggs. Marriott (1973) documented that intense bursts of alternating electric current used to electrocute female salmon to obtain their eggs increased the subsequent mortality of those eggs by about 12%. Sublethal doses were not investigated. Maxfield et al. (1971) exposed hatchery rainbow trout *Oncorhynchus mykiss* (formerly *Salmo gairdneri*) to pulsating direct current and found no apparent effects on their survival, growth, and fecundity or on the survival and development of their offspring, but the shock was applied more than a year before the fish spawned.

A simplified and portable electric barrier such as the one described here is potentially useful in remote areas when capture methods less hazardous to fish are not feasible. The 1,241 spawning chinook salmon counted during the three spawning surveys in Benjamin Creek and the estimated escapement of 8,000 adults into the Killey River indicate that this drainage is an important spawning tributary for early-run Kenai River chinook salmon.

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